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(54) PLANT FOR STORING ENERGY FROM AN ELECTRICITY SUPPLY
 SYSTEM BY MEANS OF COMPRESSED AIR AND FOR USING THE
 STORED ENERGY

(71) We, SULZER BROTHERS LIMITED, a Company organised under the Laws of Switzerland, of 8401 Winterthur, Switzerland, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to a plant for storing energy from an electricity supply system by means of compressed air and for using the stored energy during load peaks on the electricity supply system. Such a plant comprises a compressor unit consisting of at least two coupled multi-stage bladed compressors each of which except the last is connected to the following one by an intercooler, an electrical machine which either acts as a motor to drive the compressor unit to charge a compressed-air store or as an electricity generator by utilising air discharged from the store, and a gas turbine adapted to be coupled to and disengaged from the electrical machine and arranged to drive the electrical machine by using the stored compressed air.

Such a plant may be used for immediate compensation of rapid load variations in a large electricity supply system, until the output of the base load stations can be adjusted to the different load situation. During the starting up of such a plant to store operation, the air which is not yet compressed to store pressure by the compressor unit could be blown off to atmosphere via throttle elements but this would cause intolerable noise nuisance in the surroundings. The object of the invention is to prevent such noise and at the same time minimize the power drawn from the electricity supply system until the store pressure is reached for charging purposes, and also minimize the no-load power outside the charging time.

According to the present invention, a plant for storing energy from an electricity supply system by means of compressed air and for using the stored energy during load

peaks on the electricity supply system comprises: a compressor unit consisting of at least two coupled multi-stage bladed compressors each of which except the last is connected to the following one by an intercooler; an electrical machine which either acts as a motor to drive the compressor unit to charge a compressed-air store or as an electricity generator by utilising air discharge from the store; and a gas turbine adapted to be coupled to and disengaged from the electrical machine and arranged to drive the electrical machine by using the stored compressed air; at least the lowest-pressure compressor having a line connecting its outlet to its inlet via the intercooler following it, said line containing a throttle element between the outlet end of the compressor and the inlet to the intercooler.

The line from atmosphere to the lower or lowest-stage compressor may contain a shut-off valve. The lower- or lowest-stage compressor may also be provided with adjustable guide vanes. At least one higher-pressure compressor may also have a return line which leads from its outlet to its inlet via a throttle element and the intercooler following the compressor. The outlet of the last compressor may be connected, downstream of an after cooler, to its inlet by way of a return line containing throttle element.

The invention may be carried into practice in various ways but a number of plants embodying the invention will now be described by way of example with reference to the accompanying diagrammatic drawings, in which:—

Figure 1 shows a plant with a two-compressor compressor section;

Figure 2 shows a similar plant but with a somewhat modified arrangement of the intercooler;

Figure 3 shows a plant with a three-compressor compressor section; and

Figure 4 shows a similar plant with a somewhat modified arrangement of the intercoolers.

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The energy storage plants illustrated in Figures 1 to 4 are used to compensate for rapid and short-duration load variations in an electricity supply system 1 which is shown only diagrammatically in the drawing. Systems of this kind are connected via a line 2 to an electrical machine EM in the storage plant. For energy storage, the electrical machine acts as a motor while when the stored energy is delivered it acts as a generator. The electrical machine EM is connected to a compressor unit 4 via a coupling 3 so as to be detachable at standstill. The compressor unit is adapted to compress air drawn in from atmosphere via a feed line 5, and after compression this air is fed through a line 6 to a storage chamber S. The latter may, for example, be a natural or artificial cave in the ground or rock. Compressed air tanks could be used in the case of smaller plants. Pressures of from 30 to 50 atmospheres and above, e.g. up to 100 atmospheres, can be used for storage. The electrical machine EM is also connected to a gas turbine GT so as to be engaged and disengaged via a coupling 7. When operating as a generator, the electrical machine EM can transmit energy extracted from the stored compressed air to the electricity supply system 1. The gas turbine GT receives compressed air from the storage chamber S via a line 8, the compressed air advantageously first being used in a combustion chamber 9 to generate high-temperature gases in order to increase the energy that can be supplied to the electricity supply system. The turbine exhaust gases pass to atmosphere via a line 10. The storage chamber S is preferably connected to a higher-level natural or artificial lake 12 by a line 11 (Figures 1 and 2). In this way it is possible to keep the storage pressure substantially constant until the chamber S is completely empty of compressed air. The storage pressure thus corresponds to the difference between the levels O and U in the lake 12 and store S respectively.

The storage plant compressor units 4 (Figures 1 and 2) comprise a low-pressure compressor LP and a high-pressure compressor HP. The low-pressure compressor is provided with adjustable guide vanes 13 which contribute to suitable adjustment of the delivery of compressed air and the drive power absorbed by the compressor unit. An intercooler 14 is used to cool the air flowing to the high-pressure compressor HP.

In the compressor units 4 shown in Figures 1 and 2, the outlet end of each of the compressors HP and LP can be connected to its inlet end via the intercooler 14 by a return line 22, 18 respectively so that air can be recirculated through each compressor. The circulating flow and hence the pressure rise in the compressor can be adjusted as

required by means of throttle elements 23 and 17, 19 respectively.

In a compressor unit 4 (Figures 3 and 4) comprising three staged compressors LP, IP and HP, intercoolers 24, 25 respectively are provided between the low-pressure compressor LP and the medium-pressure compressor IP and between the medium-pressure compressor IP and the high-pressure compressor HP. To produce a cycle, the outlet end of each of the compressors LP, IP, HP, can be connected to its inlet end via one of the two intercoolers 24, 25 by means of the return lines 32, 35, 31 respectively. The circulating flow and hence the pressure rise in the compressor in the relevant stage can be adjusted as required by means of the throttle elements 26, 28; 27, 29 and 30 respectively. With this arrangement, the pressure level in the compressor unit can be influenced for all three compressors as with the arrangements shown in Figures 1 and 2 in respect of two compressors.

To reduce the starting-up and no-load power absorbed by the compressor unit, the delivery side of the low pressure-compressor LP (Figures 1 to 4) is connected to the intercooler 14, 24 by a line 16, 43 containing a throttle element 17, 26 and the intercooler 14, 24 is connected to the entry end of the low pressure compressor LP by a line 18, 32 respectively. The outlet end of the high pressure compressor HP (Figures 1, 3 and 4) is also connected, via a return line 22 containing a throttle element 23 (Figure 1) or a return line 31 containing a throttle element 30 (Figures 3 and 4), to the intercooler 14, 25 and the latter is connected by a line 42 to the inlet end of the high pressure compressor HP. Also, the intercooler 14, 24 (Figures 1 and 4) is also connected by the line 18, 32 to the inlet end of the low pressure compressor LP via a throttle element 19, 28 acting as a blow-off valve. The delivery line 20 of the compressor unit 4 is connected to the feed line 6 of the storage chamber S via a non-return element 21. The latter is closed on starting and under no-load conditions and does not open until the pressure in the store S is exceeded in the delivery line 20, so that then the charging up of the store can begin. When closed, a valve 15 can prevent fresh air from being supplied from atmosphere or air from reversing to atmosphere from the compressor unit.

On starting and during no-load operation of the compressor unit 4, the lowest-stage compressor LP and the associated bypass line 16, 18 (Figures 1 and 2) and 43, 32 (Figures 3 and 4) respectively, interconnecting the ends of the compressor ND, maintain a cycle which is controlled by the throttle elements 17 (Figures 1 and 2) or 26 (Figures 3 and 4) and cooled by the inter-

cooler 14 (Figures 1 and 2) or 24 (Figures 3 and 4). Given a suitable throttle element adjustment, the starting-up and no-load power can be greatly reduced.

5 Circuits for further reducing the starting-up and no-load power can also be maintained by the higher-stage compressors HP (Figures 1 to 4) and IP (Figures 3 and 4) via the bypass lines 20, 22, 42 (Figures 1 and 2) or 20, 31, 42 and 44, 35, 36 (Figures 3 and 4), these circuits being controlled by the throttle elements 23 (Figures 1 and 2) or 30 and 27 (Figures 3 and 4) and being cooled by the intercooler 14 (Figure 1) or the after cooler 21a (Figure 2) or the intercoolers 25 and 24 (Figures 3 and 4). If the valve 15 is also closed, at least the circuit through the low-pressure compressor LP can be reduced to below atmospheric pressure. The pressure in the circuits through the higher-pressure compressors can also be reduced correspondingly (if required to below atmospheric pressure) by suitable adjustment of the throttle elements 23 (Figures 1 and 2) or 30, 29 (Figures 3 and 4). A further additional reduction of the power consumption avoiding going below the surge limit, is obtained by suitable adjustment of the rotatable guide vanes 13.

20 In this way it is possible to reduce the power for starting up and accelerating and for relatively long no-load operation without blowing off to atmosphere, the said power being reduced to a fraction of the full compressor power.

30 On the starting up of the compressor plant (for example by means of the gas turbine via the couplings 7 and 3) against the back-pressure at the non-return element 21, a throttled circuit is set up via the controllable throttle element 17 (Figures 1 and 2) or 26 (Figures 3 and 4) and the cooler 14 or 24. If the valve 15 is completely closed and the guide vanes 13 set to the minimum flow cross-section, a pressure rise will occur in the individual stages of the compressor plant as far as the non-return element 21 at the start of the delivery line 6 (the non-return element 21 is closed as a result of the back pressure). Since, however, the valve 15 continues to be closed, the said pressure rises in the individual stages of the compressor unit give rise to leakages through the gland labyrinth of the individual compressors. A considerable negative pressure will develop at the entry to the lowest-stage compressor. The intermediate pressures between the individual compressors can be adjusted by means of the throttle elements in the bypass lines. Under the negative pressure forming at the entry to the low-pressure compressor, the power required to drive the compressor unit will be equivalent only to an insignificant fraction of the power absorbed by the compressor at full load. This no-load

power is converted to heat largely by compression, turbulence at the throttles and friction and this heat is dissipated by the intercoolers. The compressor unit can thus be operated continuously at full speed without appreciable losses so that in the event of a lack of power in the electricity supply system the storage plant is ready for energy generation in a very short time. During no-load operation, an optimum distribution of the pressure in each individual stage of the compressor unit can be obtained by appropriate setting of the throttle elements 17, 19, 23 and 26—30. The air drawn in through the glands in the negative pressure areas largely escapes again through the glands in the stages which are above atmospheric pressure.

70 To change over to charging of the storage chamber from no-load operation, the gas turbine GT can be disconnected from the electrical machine EM by means of the coupling 7 and the compressor unit can be operated to deliver with the valve 15 open and the throttle elements 19 and 23 in the return lines 18 and 22 respectively closed. In these conditions, as the compression power increases, the energy fed from the electricity supply system 1 to the electrical machine via the line 2 will also increase.

75 When the storage chamber has been completely charged up, the compressor unit can again be switched back to no-load operation, in which the compressor unit is kept running at speed simply by the electrical machine. The gas turbine GT remains at standstill.

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When there is a lack of power in the electricity supply 1, the gas turbine GT can very rapidly be run up to operating speed and, when the synchronous speed is reached, be coupled to the electric motor via the coupling 7. The electrical machine will then supply energy to the electricity supply system if the gas turbine output is increased. Owing to the low no-load power requirement of the compressor unit, it does not have to be disconnected from the electrical machine while the storage chamber is being discharged so that it is ready at synchronous speed for recharging after the completion of the discharge operation. The compressor can be prevented from surging on the one hand and choking on the other hand by a suitable combination of adjustments of the throttle elements. A suitable adjustment of the guide vanes in the compressor LP can also contribute to this.

The coupling 7 between the gas turbine GT and the electrical machine may be a disengageable dog clutch provided with magnetic synchronization. This enables the electrical machine already running from the electricity supply to be coupled with the running turbine in operation. It is more difficult to

couple the running electric machine to the compressor unit. It is therefore advantageous for the coupling 3 to be a mechanical clutch which can be disconnected at standstill and 5 to disconnect it only in extraordinary cases.

WHAT WE CLAIM IS:—

1. A plan for storing energy from an electricity supply system by means of compressed air and for using the stored energy during load peaks on the electricity supply system, the plant comprising: a compressor unit consisting of at least two coupled multi-stage bladed compressors each of which except the last is connected to the following one by an intercooler; an electrical machine which either acts as a motor to drive the compressor unit to charge a compressed-air store or as an electricity generator by utilising air discharge from the store; and a gas turbine adapted to be coupled to and disengaged from the electrical machine and arranged to drive the electrical machine by using the stored compressed air; at least the lowest-pressure compressor having a line connecting its outlet to its inlet via the intercooler following it, said line containing a throttle element between the outlet end of the compressor and the inlet to the intercooler.
2. A storage plant as claimed in Claim 1 in which the line from atmosphere to the lower- or lowest-stage compressor contains a shut-off valve.

3. A storage plant as claimed in Claim 1 or Claim 2 in which at least the lower- or lowest-stage compressor has adjustable guide vanes.

4. A storage plant as claimed in Claim 1 or Claim 2 or Claim 3 in which at least one higher-pressure compressor also has a return line which leads from its outlet to its inlet via a throttle element and the intercooler following the compressor.

5. A storage plant as claimed in Claim 1 or Claim 2 or Claim 3 in which at least one higher-pressure compressor has a return line leading from the compressor outlet to its inlet end via a throttle element and the intercooler preceding the compressor.

6. A storage plant as claimed in Claim 1 or Claim 2 or Claim 3 in which the outlet of the last compressor is connected, downstream of an after cooler, to its inlet by way of a return line containing a throttle element.

7. A plant for storing energy from an electricity supply system by means of compressed air and for using the stored energy during load peaks on the electricity supply system, the plant being substantially as described herein with reference to Figure 1 or Figure 2 or Figure 3 or Figure 4 of the accompanying drawings.

KILBURN & STRODE,
Chartered Patent Agents,
Agents for the Applicants.

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4 SHEETS

COMPLETE SPECIFICATION

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Sheet 1

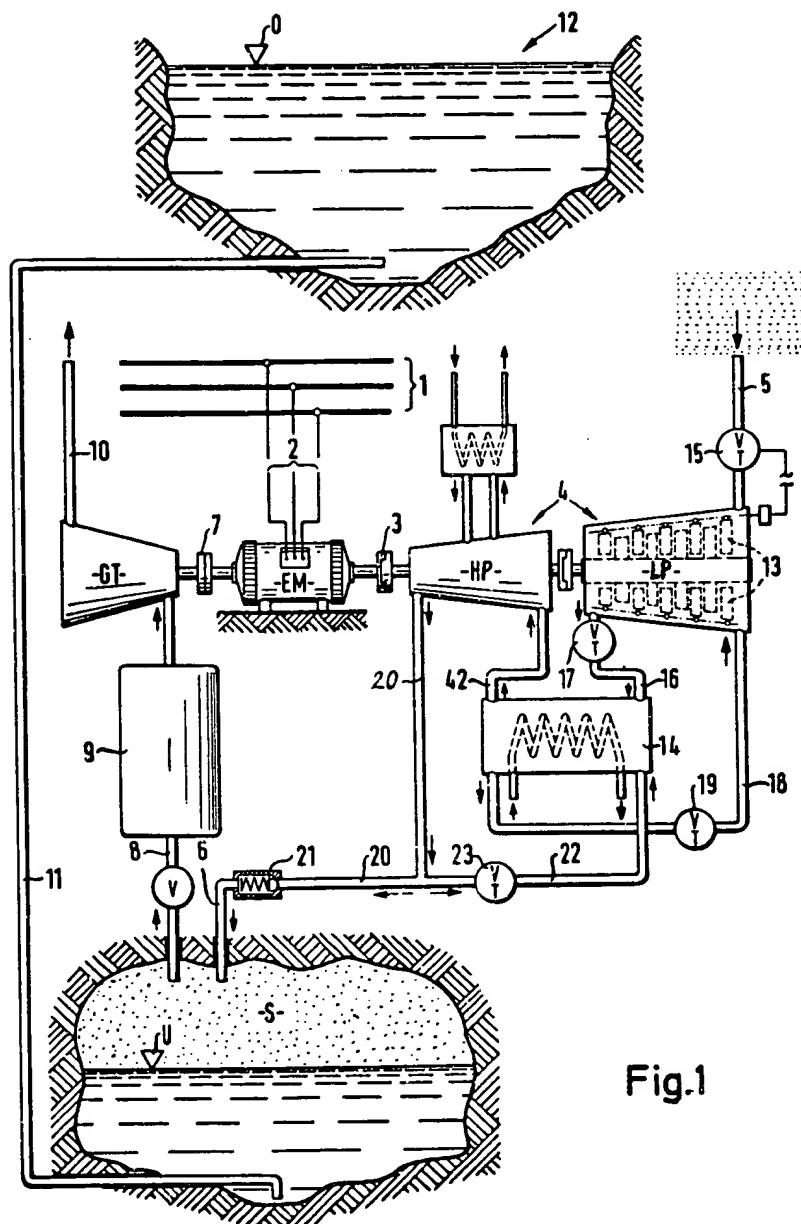


Fig.1

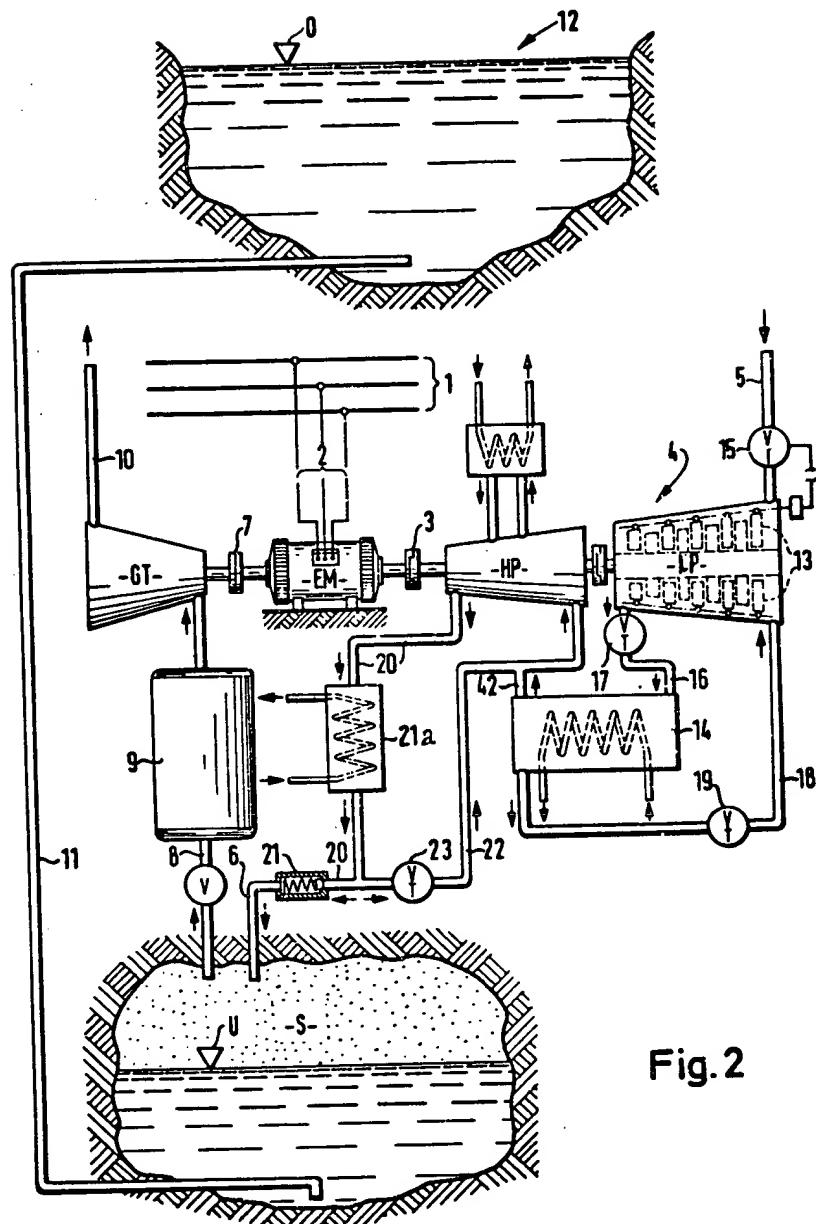


Fig. 2

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4 SHEETS

COMPLETE SPECIFICATION

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Sheet 3

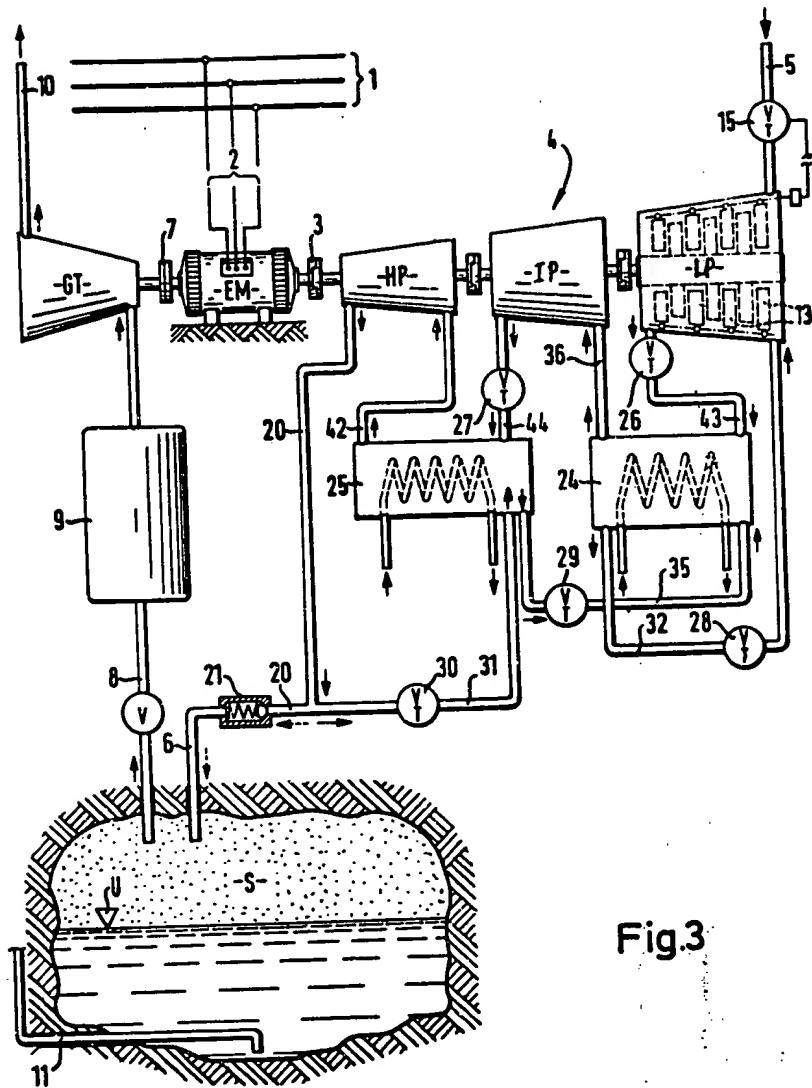


Fig.3

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COMPLETE SPECIFICATION

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Sheet 4

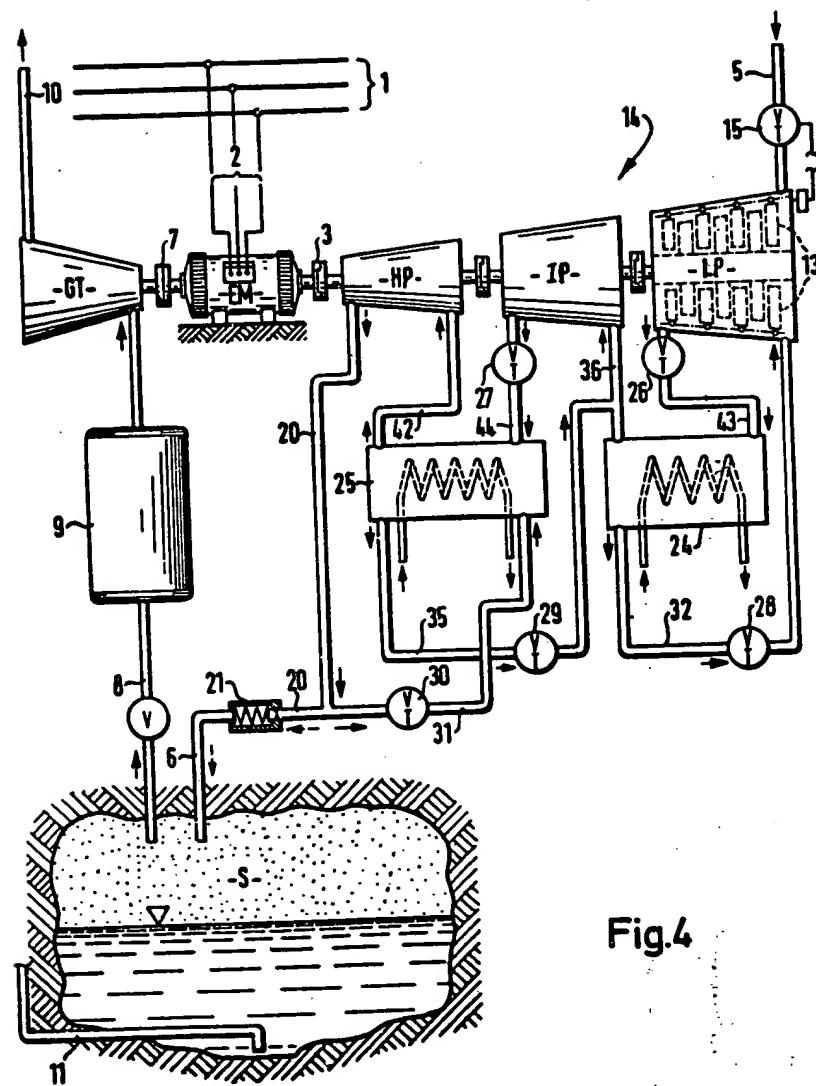


Fig.4